

TRANSLATOR APPARATUS FOR TWO COMMUNICATION NETWORKS

BACKGROUND OF THE INVENTION

Field of the Invention

5 This invention relates to translator apparatus and, more particularly, to such a translator apparatus for two communication networks.

Background Information

10 In power management control and data acquisition systems, a variety of power monitoring or control devices are connected to a common bus, which allows such devices to communicate with a server. One standard protocol employed for communicating between the server and the power control and monitoring devices is the Modbus RTU standard. A wide range of commercially available Modbus RTU Servers may be employed for a variety of applications. For example, all major electrical distribution companies have a similar product. Typically, the servers may support any generic Modbus RTU compliant device.

15 For example, as shown in Figure 1, a programmable logic controller (PLC) Modbus RTU master 2 communicates with up to about 32 or 64 Modbus slaves 4,6,8 (*e.g.*, overload relays, meters, circuit breakers) over an RS-485 based communication channel 10.

20 U.S. Patent No. 5,862,391 discloses a Modbus concentrator, which is generally a multiple channel data converter/multiplexer. The concentrator translates data between two protocols for multiple metering and protective devices (*i.e.*, between General Electric's Commnet peer-to-peer network protocol and the industry standard Modbus RTU protocol). The concentrator acts as a pseudo host for Commnet devices and as a pseudo slave for each device in the Modbus RTU network. The concentrator creates virtual Modbus devices for every physical Commnet device attached to its multiple channels. Multiple channels allow parallel processing for data conversion, improving the throughput of the network in which it is utilized. Further, the concentrator auto-configures itself by seeking all the devices attached in the Commnet channels and storing this information in a configuration database, which is used to determine address conflicts among the attached Commnet devices.

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Existing Modbus slaves have identical variables (e.g., phase A current, I_A ; phase A-B line-to-line voltage, V_{AB}) or constant parameters in various Modbus registers. Such variables or constant parameters are not only inconsistent from one manufacturer of Modbus slaves to other manufacturers of Modbus slaves, but are also inconsistent from one Modbus slave to another Modbus slave of the same manufacturer. Hence, for various Modbus slaves, there is a separate Modbus register map listing the Modbus registers where the specific variables or constant parameters exist. For example, the phase A current, I_A , may be at one register (e.g., 12A4H) for a first product and may be at a second different register (e.g., 1145H) for a second product. Accordingly, programming a Modbus master is both time consuming and potentially error prone, since for various Modbus slave devices, the same variable or constant parameter may exist in a different register location with respect to the other various Modbus slaves. Hence, there exists the possibility that each query for an identical variable or constant parameter will be different.

The INCOM (INDustrial COMmunications) Network provides two-way communication between an INCOM network master and a variety of products such as, for example, electrical interrupting devices, circuit breakers, digital meters, motor overload relays, monitoring units and a wide range of industrial products. Control and monitoring is carried out over a network consisting of dedicated twisted pair wires. Preferably, a semi-custom integrated circuit provides a simple, low cost interface to the network. For example, a Sure Chip Plus™ microcontroller enables the electrical interrupting device to communicate with the INCOM network. This integrated circuit provides various network functions such as, for example, carrier generation and detection, data modulation/demodulation, address decoding, and generation and checking of a 5-bit cyclic redundant BCH error code.

An INCOM communication module, which may be otherwise known as a PONI "Product Operated Network Interface," may act as an interface device between a remote personal computer PC and the electrical meter, protector or control communicating device that does not have a built-in INCOM transceiver.

The INCOM network employs a simple two-wire asynchronous communication line, which is daisy chained to the several devices. A master device

digitally addresses each of the slave devices in a master/slave relationship for the purpose of gathering the data generated by the individual units for central processing. An INCOM network can have one master and up to 1000 slaves. The INCOM communications protocol is based on 33-bit message packets. A typical INCOM network transaction consists of one or more 33-bit message packets transmitted by the master, and one or more 33-bit message packets transmitted by a slave in response.

Examples of the INCOM network and protocol are disclosed in U.S. Patent Nos. 4,644,547; 4,644,566; 4,653,073; 5,315,531; 5,548,523; 5,627,716; 5,815,364; and 6,055,145, which are incorporated by reference herein.

The assignee of the present invention has undertaken the design of new products (*i.e.*, Plug-'n-Play (or PnP) products), which respond to the INCOM protocol, in order to return the same objects (*e.g.*, phase A current, phase B voltage) using the same set of corresponding INCOM commands. This provides a consistent set of commands to obtain identical objects from INCOM devices. Nevertheless, there exists various legacy products, which have an inconsistent command structure and which return the same objects using a different set of corresponding INCOM commands. For example, one legacy product returns phase A current with one INCOM command, while a second legacy product returns the same current with a different INCOM command.

Any suitable computer or programmable device (*e.g.*, with an RS-232C communications port; PC XT/AT bus) may function as an INCOM network master. An RS-232C based INCOM network master employs a gateway device such as the MINT (Master INCOM Network Translator). The gateway device converts the 10 byte ASCII encoded hexadecimal RS-232C messages to or from 33-bit binary messages used on the INCOM local area network.

An IBM XT or AT compatible personal computer alternatively employs the CONI (Computer Operated Network Interface) for interfacing to the INCOM network. The CONI employs a direct PC-bus interface, which provides a more efficient network interface than that of the MINT.

There are two basic types of INCOM messages: control messages and data messages. The messages are 33 bits in length and are sent with the Least

Significant Bit (LSB) first. The INCOM chip generates a number of the bits including the Start bits, Stop bit and BCH error detection code. The format for an INCOM-control message is shown in Table 1.

Table 1

Bit Number(s)	Mnemonic	Definition
1-0	STR	Start Bits = 11
2	C/D	Control Bit = 1 for Control Messages
6-3	INST	Instruction Field
10-7	COMM	Command Field
22-11	ADDRESS	Address of Product (Slave Device)
26-23	SCOMM	SubCommand Field
31-27	BCH	BCH error detection field
32	STP	Stop Bit = 0

The format for an INCOM-Data message is shown in Table 2.

Table 2

Bit Number(s)	Mnemonic	Definition
1-0	STR	Start Bits = 11
2	C/D	Control Bit = 0 for Data Messages
10-3	BYTE0	8-bit data field (Bit 3 = b0)
18-11	BYTE1	8-bit data field (Bit 11 = b0)
26-19	BYTE2	8-bit data field (Bit 18 = b0)
31-27	BCH	BCH error detection field
32	STP	Stop Bit = 0

There are two types of INCOM slave devices (products): a stand-alone slave, and an expanded mode slave. The stand-alone slave is a device on an INCOM network that can control one digital output and monitor up to two status (digital) inputs. An example of a stand-alone slave device is an addressable relay marketed by Eaton/Cutler-Hammer of Pittsburgh, Pennsylvania. A stand-alone slave device uses INCOM control messages exclusively for communications.

The expanded mode slave is a device on an INCOM network that can send and/or receive data values over the INCOM network including, for example, analog and digital I/O data, configuration or setpoint information, and trip data. Examples of such devices include IQ Data Plus II Line Metering Systems, Digitrip RMS 700 and 800 Trip Units, and IQ 1000 and IQ 500 Motor Protection Systems, all

marketed by Eaton/Cutler-Hammer. An expanded mode slave device uses INCOM control messages and INCOM data messages for communications.

There are seven examples in which an expanded mode slave product, in response to a command from the master, may send a return-command message to the master. These include: (1) Acknowledge (ACK) Reply; (2) Negative Acknowledge (NACK) Reply; (3) Product Buffer Not Yet Available; (4) Sub-network Product Not Responding; (5) Checksum Error; (6) Downloaded Value Out of Range; and (7) Product Not in a State That Allows the Requested Action.

Some INCOM commands require the product to transmit an acknowledge (ACK) message. The positive acknowledge indicates that the product accepted the present command or the data transmission was completed successfully. The format of the ACK message, ignoring the Start bits, Stop bit and BCH error detection code, includes: (1) C/D = 1; (2) INST = 3; (3) COMM = 1; (4) ADDRESS = address of slave (some products may employ address 000H or FFFH; other products can assume any address in the 12 bit address space); and (5) SCOMM = 0. The product will transmit a negative acknowledge (NACK), rather than an ACK, in response to certain conditions. The negative acknowledge indicates that the product has not accepted the COMM and SCOMM command request. The format of the NACK message, ignoring the Start bits, Stop bit and BCH error detection code, includes: (1) C/D = 1; (2) INST = 3; (3) COMM = 1; (4) ADDRESS = address of slave (some products may employ address 000H or FFFH; other products can assume any address in the 12 bit address space); and (5) SCOMM = 1.

For example, some conditions for which a product will respond with a NACK include: (1) the product received an INCOM control message that it does not recognize (*e.g.*, an INCOM control message with INST=3, and COMM and SCOMM values that it does not support); and (2) the PONI received an INCOM control message that it cannot process due to a communications failure between the PONI and the product. Products only respond to INCOM messages containing a good BCH value.

Examples of standard master-to-slave commands for the Integrated Monitoring, Protection, And Control Communication (IMPACC) protocol are shown

below, in Table 3. All of these commands employ $C/D = 1$ and, thus, only the INST, COMM, and SCOMM specifications are provided. The words transmit and receive in the command definitions are with respect to the product. If the message is a transmit command, then the result will be the transmission of data from the product to the master. On the other hand, a receive command that is transmitted from the master to the product will be followed by data transmissions from the master, which are to be received by the product. Table 3 shows six classes of standard master-to-expanded mode slave commands.

Table 3

<u>Command</u>	<u>INST</u>	<u>COMM</u>	<u>SCOMM</u>
Standard slave-buffer transmissions	3	0	0-F
Standard system management buffer transmissions	3	A	3-7
Product specific slave-buffer transmissions	3	C	8-F
Standard slave actions	3	D	0,1,3
Standard master-buffer transmissions	3	D	8-F
Product specific master-buffer transmissions	3	F	8-F
Broadcast Command	D	0-F	0-F

A few examples of these communications data buffers are discussed, below. A standard data buffer includes a specification for the formatting of analog data in engineering units. For example, the IMPACC 24-Bit Floating Point Number Format permits the IMPACC family to include a number of products that send similar analog parameters (*e.g.*, currents, voltages). Each parameter is sent as a single data transmission with the three bytes defined as follows: (1) BYTE0 is the low-order byte of 16-bit magnitude; (2) BYTE1 is the high-order byte of 16-bit magnitude; and (3) BYTE2 is the scale byte, wherein the BYTE2 bit definitions (b7-b0) are as follows: (a) for bit b7: 0 indicates that the value in BYTE0 and BYTE1 is a 16-bit unsigned integer, and 1 indicates that the value in BYTE0 and BYTE1 is a 16-bit signed integer; (b) for bit b6: 0 indicates that the data is invalid, and 1 indicates that the data is valid; (c) for bit b5: 0 indicates a multiplier as a power of 2, and 1 indicates a multiplier as a power of 10, and (d) the bits b4-b0 represent the multiplier's exponent in 5-bit signed integer form. This allows a magnitude of multiplier to range from 2^{-16} to 2^{+15} (for b5 = 0), or 10^{-16} to 10^{+15} (for b5 = 1).

Table 4 shows the Standard Expanded Mode Slave-Buffer Transmissions (for COMM = 0 and SCOMM = 0-F).

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Table 4

	<u>INST</u>	<u>COMM</u>	<u>SCOMM</u>	<u>Command Definition</u>
	3	0	0	Transmit Fast-Status.
10	3	0	3	Transmit All Standard Buffers
	3	0	5	Transmit Current Buffer
	3	0	6	Transmit Line-to-Line Voltage Buffer
	3	0	7	Transmit Line-to-Neutral Voltage Buffer
	3	0	8	Transmit Power Buffer(1)
15	3	0	9	Transmit Power Buffer(2)
	3	0	A	Transmit Energy Buffer
	3	0	B	Transmit Saved Energy Buffer
	3	0	C	Transmit Saved Reactive Energy Buffer
20	3	0	F	Receive Expanded Transmit Buffer Number

Table 5 shows the Buffer Numbers for the Receive Expanded Transmit Buffer Number command (for COMM = 0 and SCOMM = F).

Table 5

Buffer	
No.	Buffer Description
5	N=1 Transmit Temperature Buffer
	N=2 Transmit Demand Currents Buffer
	N=3 Transmit Current Buffer
	N=4 Transmit Line-Line Voltage Buffer
	N=5 Transmit Line-Neutral Voltage Buffer
10	N=6 Transmit Power Buffer
	N=7 Transmit Per-Phase Power Buffer
	N=8 Transmit System Energy Buffer
	N=9 Transmit THD Buffer
	N=10 Transmit Demand Current Buffer (w/ time stamp)
15	N=11 Transmit Per-Phase Demand Current Buffer (w/ time stamp)
	N=12 Transmit Demand Power Buffer (w/ time stamp)
	N=13 Transmit Min/Max Current Buffer (w/ time stamp)
	N=14 Transmit Min/Max L-L Voltage Buffer (w/ time stamp)
	N=15 Transmit Min/Max L-N Voltage Buffer (w/ time stamp)
20	N=16 Transmit Min/Max PF-Displacement Buffer (w/ time stamp)
	N=17 Transmit Min/Max PF-Apparent Buffer (w/ time stamp)
	N=18 Transmit Min/Max Power/Frequency Buffer (w/ time stamp)
	N=19 Transmit Min/Max Current %THD Buffer (w/ time stamp)
	N=20 Transmit Min/Max Voltage %THD Buffer (w/ time stamp)
25	N=21 Transmit Crest Factor Buffer
	N=22 Transmit Min/Max per-phase real power (w/ time stamp)
	N=23 Transmit Min/Max per-phase reactive power (w/ time stamp)
	N=24 Transmit Min/Max per-phase VA (w/ time stamp)
	N=25 Transmit Min/Max Currents Buffer (w/o time stamp)
30	N=26 Transmit Demand Currents Buffer (w/o time stamp)
	N=27 Transmit Demand Power Buffer (w/o time stamp)
	N=28 Transmit Min/Max Voltage Buffer (w/o time stamp)
	N=29 Transmit Min/Max Power/Frequency/PF Buffer (w/o time stp.)
	N=30 Transmit Min/Max Current %THD Buffer (w/o time stamp)
35	N=31 Transmit Min/Max Voltage %THD Buffer (w/o time stamp)
	N=32 Transmit Min/Max Current THD Magnitude Buf. (w/ time stp.)
	N=33 Transmit Min/Max Voltage THD Magnitude Buf. (w/ time stp.)
	N=34 Transmit Whole Load Center Energy Buffer

The Transmit All Standard Buffers command definition (3 0 3 of Table 4) covers the standard buffers as defined by INST=3, COMM=0, and SCOMM=5 through A.

The Transmit Current Buffer (3 0 5 of Table 4) response consists of four data messages, each containing an IMPACC 24-bit Floating Point Number, with the current units being expressed in amperes. The four messages respectively include:

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communication networks.

SUMMARY OF THE INVENTION

There exists the need to consistently pass objects from slave legacy products and PnP (Plug-‘n-Play) products to Modbus RTU registers. The present invention eliminates the variability in slave register maps and slave object/command maps, which can be prone to user error, and also minimizes the amount of documentation needed for an entire line of Modbus slaves. The present invention is directed to a translator apparatus for a first communication network, such as a Modbus RTU network having a register map of values, and a second communication network, such as an INCOM network having a plurality of slave INCOM devices with diverse object/command assignments, or such as a Modbus RTU network having a plurality of slave devices with diverse register maps of values.

As one aspect of the invention, a translator apparatus comprises: a first transceiver adapted to interface a first communication network having a register map of values; a second transceiver adapted to interface a second communication network having a plurality of slave devices, the slave devices having a plurality of different maps of objects and commands; and a processor comprising: a first interface to the first transceiver, a second interface to the second transceiver, and a communication routine adapted to: receive a request based upon the register map through the first transceiver related to at least one of the objects of one of the slave devices, the at least one of the objects of one of the slave devices being responsive to a first command, the at least one of the objects of another one of the slave devices being responsive to a different second command, send a command through the second transceiver related to the at least one of the objects of one of the slave devices, the command being selected from a corresponding one of the maps of objects and commands, receive a response based upon the command through the second transceiver related to the at least one of the objects of one of the slave devices, and send a response based upon the register map through the first transceiver related to the at least one of the objects of one of the slave devices.

As another aspect of the invention, a translator apparatus comprises: a first transceiver adapted to interface a Modbus RTU network having a first register map of values; a second transceiver adapted to interface a slave communication

network having a plurality of slave devices, the slave devices having at least one second register map of values, the second register map being different from the first register map of values; and a processor comprising: a first interface to the first transceiver, a second interface to the second transceiver, and a communication routine adapted to: receive a request based upon the first register map through the first transceiver related to at least one of the values of one of the slave devices, the at least one of the values of one of the slave devices having a first position in the first register map and a second different position in the second register map, send a request based upon the second register map through the second transceiver related to the at least one of the values of one of the slave devices, receive a response based upon the second register map through the second transceiver related to the at least one of the values of one of the slave devices, and send a response based upon the first register map through the first transceiver related to the at least one of the values of one of the slave devices.

BRIEF DESCRIPTION OF THE DRAWINGS

A full understanding of the invention can be gained from the following description of the preferred embodiments when read in conjunction with the accompanying drawings in which:

Figure 1 is a block diagram of a programmable logic controller (PLC) Modbus RTU master and a plurality of Modbus slaves.

Figure 2 is a block diagram of a Modbus Master INCOM Network Translator Module providing communication between a Modbus RTU network and a plurality of INCOM slaves in accordance with the present invention.

Figure 3 is an isometric view of the Modbus Master INCOM Network Translator Module of Figure 2.

Figure 4 is a block diagram in schematic form of the Modbus Master INCOM Network Translator Module of Figure 2.

Figure 5 is a flowchart of the main loop of the processor of the Modbus Master INCOM Network Translator Module of Figure 4.

Figures 6A-6C, 6D and 7 are flowcharts of the query handler, the message processor and the query response handler, respectively, of the processor of the Modbus Master INCOM Network Translator Module of Figure 4.

Figure 8 is a block diagram in schematic form of a Modbus Master
5 Modbus Network Translator Module in accordance with another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will be described as applied to a network translator
10 between a Modbus RTU network and an INCOM (INDustrial COMmunications) network marketed by Eaton/Cutler-Hammer, although the invention is applicable to a network translator between a first communication network, such as a Modbus RTU network, and any suitable slave or native language network (*e.g.*, without limitation, INCOM; another Modbus RTU network; Multilin marketed by General Electric;
15 DataHighway Plus marketed by Allen-Bradley; BACnet marketed by Alerton Technologies, Inc.; Modbus RTU I/O modules marketed by Arco Mag).

Referring to Figure 2, a Modbus RTU serial network 12 includes a Modbus master 14, a plurality of Modbus slaves 16,18,20, and a Modbus network cable 22. The exemplary Modbus slave 20 is a Plug 'N Play Modbus / native
20 language translator apparatus, which functions as a Modbus RTU network slave and a native language network master. In the exemplary embodiment, the Modbus slave 20 is a mMINT (Modbus Master INCOM Network Translator) module which provides communication between the Modbus RTU network 12 and an INCOM (INDustrial COMmunications) network 24. This mMINT module 20 is transparent to the Modbus
25 RTU network 12. It communicates to the Modbus master 14 on the Modbus RTU network 12 using the Modbus RTU (Remote Terminal Unit) protocol. It communicates to the INCOM network 24 using the IMPACC protocol.

The exemplary native language INCOM network 24 includes the exemplary mMINT module 20, a plurality of slave devices 26,28,30,32,34, and an
30 INCOM network cable 36. The mMINT module 20 is a slave device on the Modbus

RTU network 12 and, as such, interfaces with the Modbus master 14, which exchanges register objects with the mMINT module 20.

In the exemplary embodiment, the mMINT module 20: (1) handles generic passthrough commands (Modbus/INCOM/Modbus); (2) passes register objects from legacy slave products (*e.g.*, slaves 26,28) and newer PnP (Plug-'n-Play) slave products (*e.g.*, slaves 30,32) to Modbus RTU registers; (3) employs data in IEEE Floating Point format and fixed point; (4) provides Modbus RTU communication data transfer rates of 1200, 9600 or 19200 baud with 1 start bit, 8 data bits and one stop bit; (5) interfaces up to 32 slave products connected to the INCOM network port 38 (up to 247 unique Modbus addresses are possible); (6) provides a flashing status LED 70 (Figure 3) to indicate an active module; (7) employs LEDs 66,68 (Figure 3) for INCOM transmit and receive communications exchanges; (8) employs LEDs 62,64 (Figure 3) for Modbus RS-485 transmit and receive communications exchanges; and (9) receives input power for the module from either 120 VAC or 48 to 125 VDC.

As discussed below in connection with Table 6, the mMINT module 20 includes a primary constant array (P) 40 of commands, which is a constant array of records of native language INCOM elements employed to obtain a specific object from a slave device, which speaks the native INCOM language. The mMINT module 20 also includes a secondary constant array (S) 42 of commands.

In accordance with the present invention, the contents of Modbus registers in the single Modbus register map 44 are INCOM product objects (*e.g.*, IA, phase A current; IB, phase B current; IC, phase C current; VA, phase A voltage; VB, phase B voltage; VC, phase C voltage). The mMINT module 20 ensures that unique objects reside in identical registers independent of the INCOM slave products 26,28,30,32,34. Consequently, for all INCOM slave products there is a single Modbus register map 44 of objects as shown, for example, below in Table 12. INCOM objects in this table occupy two registers, such as 1202H and 1203H for IEEE floating point format for IA, phase A current, and four registers, such as 18A8H, 18A9H, 18AAH and 18ABH for net energy.

The exemplary mMINT module 20 is transparent to the Modbus master 14 and responds to every address of INCOM slave products attached thereto. For example, the slave devices 26,28,30,32,34 may have INCOM product addresses 10,15,20,22,247, respectively. As a result, the mMINT module 20 is responsive to corresponding Modbus network addresses 10,15,20,22,247, respectively, in the RTU communications mode. As a further example, the Modbus slave devices 16,18 may be response to Modbus network addresses 21,23, respectively, and there are, thus, no mMINT slave devices at the corresponding Modbus product addresses.

The exemplary PnP INCOM slave devices 32,30 have respective object/command maps 46,48, which are consistent with the single Modbus register map 44 and Table 12. In this example, a first INCOM command is employed to read the three current objects IA, IB, IC; and a second INCOM command is employed to read the three voltage objects VA, VB, VC. On the other hand, the exemplary legacy INCOM slave devices 28,26,34 have respective object/command maps 50,52,53, which are inconsistent with the single Modbus register map 44 and Table 12. These devices employ four different INCOM commands to read the three current objects and the three voltage objects. However, in accordance with the present invention, the mMINT module 20 advantageously translates the diverse object/command assignments (e.g., without limitation, maps (1) 46,48; (2) 50; and (3) 52 of Figure 2) of the slave INCOM devices in order to provide the single Modbus register map 44 for communications between the Modbus master 14 through the mMINT module 20 and with the legacy INCOM slave devices 26,28.

As shown in Figure 3, the mMINT module 20 includes three connectors 54,56,58. In the exemplary embodiment, the connector 54 is a 5-pin input power connector in which pin 1 is chassis ground, pins 2 and 3 are VAC neutral (or VDC common), and pins 4 and 5 are 120 VAC, 60 Hz (or 48-125 VDC). The INCOM connector 56 is a 3-pin connector, which provides the interface to the INCOM network 24 of Figure 2. Pins 1 and 2 are the INCOM carrier network twisted pair, and pin 3 is the shield. The shield wire is connected to ground at the INCOM network port 38 (Figure 2) end only. The shielding is interconnected where the slave devices 26,28,30,32,34 are daisy chained. The Modbus RS-485 connector 58 is a 5-

pin connector, which provides the interface to the Modbus RTU network 12 of Figure 2. Pin 1 is the RS-485 Network-A non-inverting differential connection, and pin 2 is the RS-485 Network-B inverting differential connection for the Modbus RTU network 12. Pin 3 is common, pin 4 is the shield, and pin 5 is not used.

Figure 3 also shows five exemplary status LEDs 60 (*e.g.*, green) for the mMINT module 20. The Modbus RS-485 Network Rx LED 62 is lighted whenever the module is receiving from the Modbus RTU network 12 of Figure 2. The Modbus RS-485 Network Tx LED 64 is lighted whenever the module is transmitting on the Modbus RTU network. The INCOM Network Rx LED 66 is lighted whenever the module 20 is receiving from the INCOM network 24 of Figure 2. The INCOM Network Tx LED 68 is lighted whenever the module is transmitting on the INCOM network. The Status LED 70 is flashing whenever the module 20 is powered up and when the module's micro-controller 72 of Figure 4 is executing instructions.

Referring to Figure 4, the mMINT module 20 includes the micro-controller 72, a Modbus transceiver 74, an INCOM transceiver 76 and a suitable power supply 78. The micro-controller 72 includes a suitable CPU (μ P) 80, a UART 82 for interfacing the Modbus transceiver 74, an INCOM port 84 for interfacing the INCOM transceiver 76, memory (MEM) 86 (*e.g.*, RAM, non volatile RAM, stack, EEPROM, and ROM with executable code), an output port 88 for driving the LEDs 60, and an input port 90 for inputting from switch SW2 92. The Modbus transceiver 74 is adapted to interface the Modbus RTU network 12 having the Modbus register map of values 44 of Figure 2. The INCOM transceiver 76 is adapted to interface the INCOM network 24 including the INCOM slave devices 26,28,30,32,34 having one or more different object/command maps 50,52.

Other switches SW1 94 and SW3 96 are associated with the INCOM connector 56 and the Modbus connector 58, respectively. Preferably, the switches 92,94,96 are conventional dual-inline-package (DIP) switches having a plurality of individual switches, which are accessible from the top front (not shown) of the mMINT module 20 of Figure 3. The μ P 80 also includes suitable timing and other resources for supporting communications on the two communication networks 12,24.

The INCOM termination switch (SW1) 94 (*e.g.*, interfacing a 100 Ω termination resistor) is moved to the “ON” position only when the module 20 is the last INCOM unit in a chain of units (*e.g.*, as shown in Figure 2) or if it is a single unit. The Modbus RS-485 baud rate switch (SW2) 92 configures the data transfer rate for the Modbus RTU network 12. There are three exemplary switches (not shown) in switch SW2 92, two of which are moved to either the “CLOSE” (0) or the “OPEN” (1) position based on the selected baud rate (*e.g.*, 00x = 1200, 01x = 9600, and 10x = 19200). A third switch is for Modbus diagnostics. The mMINT module 20 can be assigned a Modbus address. For the mMINT module 20 to respond to a diagnostic query related to address 248 on the Modbus network 12, that third switch of switch SW2 92 is moved to the “OPEN” (1) position as discussed below in connection with Table 11. Otherwise, that switch is in the “CLOSE” (0) position. Finally, the Modbus Termination Dip Switch (SW3) 96 (*e.g.*, interfacing a 121 Ω termination resistor) is moved to the “ON” position only when it is the last unit in a chain of units or if it is a single unit (not shown).

As shown below in Table 6, the primary constant array (P) 40 of Figure 2 has an ordered sequence with respect to associated Modbus register addresses (Reg #), such that the index to a specific record is a function of the Modbus register address. Each record of this array has an element (“2ndry cmd ndx”), which contains a start index into the secondary constant array (S) 42 of Figure 2 (Table 7, below). If there is no corresponding secondary array record, then this element is set equal to -1. As shown in Table 7, the structure of each record of the secondary constant array (S) 42 is identical to that of the primary constant array 40. However, unlike the records of the primary constant array 40, the records of the secondary constant array 42 do not have an ordered sequence with respect to associated Modbus register addresses (Reg #). Each record of this array 42 has an element (“ndx lnk”), which contains an index to the next record within this array 42, which could possibly be used to obtain the associated object. This element is equal to -1 if no additional record exists, which could possibly be used to obtain the object of interest.

Table 6

Reg #		fix pt	object	cmd	sub	#msgs	Expand Buf #				offset	frmt#	2ndry
IEEE	fixed	scale	name	/inst	cmd						bytes		cmd
	point												ndx
1200	1800	x1	status	03	10	1					0	48	0
1202	1802	x10	I _A	03	F0	7	0	0	0	3	3	13	1
1204	1804	x10	I _B	03	F0	7	0	0	0	3	6	13	2
1206	1806	x10	I _C	03	F0	7	0	0	0	3	9	13	3
1208	1808	x10	I _{load}	03	F0	7	0	0	0	3	C	13	4
120A	180A	x10	I _N	03	F0	7	0	0	0	3	F	13	4
120C	180C	x10	I _{avg}	03	F0	7	0	0	0	3	12	13	-1
120E	180E	x10	V _{AB}	03	F0	5	0	0	0	4	3	13	5
1210	1810	x10	V _{BC}	03	F0	5	0	0	0	4	6	13	6
1212	1812	x10	V _{CA}	03	F0	5	0	0	0	4	9	13	7
122A	182A	x1	3 _{grndPwr}	03	F0	9	0	0	0	6	3	13	11
	•		•		•						•		•
	•		•		•						•		•
N/A	18A0	x10	fwd WH	03	F0	0D	0	0	0	8	3	54	24
N/A	18A4	x10	rev WH	03	F0	0D	0	0	0	8	7	54	25
N/A	18A8	x10	WH	03	F0	0D	0	0	0	8	11	54	13
N/A	18AC	x1	Id VARh	03	F0	0D	0	0	0	8	F	54	-1
N/A	18B0	x1	lag VARh	03	F0	0D	0	0	0	8	13	54	-1
N/A	18B4	x1	VARh	03	F0	0D	0	0	0	8	17	54	-1
N/A	18B8	x1	VAhrs	03	F0	0D	0	0	0	8	1B	54	28
	•		•		•						•		•
	•		•		•						•		•

Table 6 includes portions of two typical primary constant arrays of commands for the exemplary INCOM native language. Table 6 assumes an exemplary base address of 40000H and, thus, for example, object I_A would be at registers 41202H and 41802H, although a wide range of base addresses (*e.g.*, without limitation, 30000H) may be employed. The first array (upper portion of Table 6) employs exemplary IEEE floating point objects at registers in the register space beginning at 1200H (through and including 122AH), and each object occupies two registers (*i.e.*, 32 bits). The first array also employs fixed point objects at registers in the register space beginning at 1800H (through and including 182AH), and each object occupies two registers (*i.e.*, 32 bits). In the second array (lower portion of Table 6), IEEE floating point objects are not employed (N/A) and each object

occupies four registers (*i.e.*, 64 bits) and begins at register 18A0H (through and including 18B8H).

The first four columns of Table 6 are for ease of illustration and are not part of the exemplary array 40. Each row is a record, which record consists of ten elements: (1) cmd/inst; (2) sub cmd; (3) # msgs; (4)-(7) Expand Buf #; (8) offset bytes; (9) frmt #; and (10) '2ndry cmd ndx', with each column being an element of the record. The tenth element ('2ndry cmd ndx') is the index into the secondary constant array 42, where the first (of perhaps several) additional commands are available for use in obtaining a particular record object from a particular INCOM slave device.

This structure of the two arrays 40 (P) and 42 (S) is employed because an object is not necessarily retrieved with the identical command by every native language INCOM device.

The objects of the first (upper) array are assigned register numbers in monotonically increasing order (*e.g.*, 1200H and 1800H, 1202H and 1802H, 1204H and 1804H), that provides a mechanism for calculating the index into these arrays.

For example, the index, 3, to phase C current (I_C) is obtained from $(1206H - 1200H) / 2 = 3$. As another example, the index, 2, to the watt hour (WH) object of the second (lower) array is obtained from $(18A8H - 18A0H) / 4 = 2$.

TABLE 6

Table 7

Reg #	Object name	nbr	Cmd/inst	sub cmd	# msgs	Expand Buf #				offset (bytes)	frmt #	ndx lnk
1200	status	0	03	00	1					0	48	29
1202	I _A	1	03	50	4					0	13	-1
1204	I _B	2	03	50	4					3	13	-1
1206	I _C	3	03	50	4					6	13	-1
1208	I _X	4	03	50	4					9	13	-1
120E	V _{AB}	5	03	60	3					0	13	-1
1210	V _{BC}	6	03	60	3					3	13	-1
1212	V _{CA}	7	03	60	3					6	13	-1
	•			•						•		•
	•			•						•		•
1228	3 _{grealPwr}	11	03	80	3					0	13	-1
1264	pwr dmnd	12	03	80	3					3	13	-1
18A8	WH	13	03	80	3					6	54	17
1232	freq	14	03	90	3					0	13	-1
122A	3 _{grealPwr}	15	03	90	3					3	13	-1
1230	3 _{gntApp}	16	03	90	3					6	13	-1
18A8	WH	17	03	A0	1					0	54	23
	•			•						•		•
18AC	ld VAR	21	03	C0	4					3	13	-1
18B0	lag VAR	22	03	C0	4					7	13	-1
18A8	WH	23	03	F0	3				34	3	54	-1
18A0	fwd WH	24	03	F0	6				35	3	54	26
18A4	rev WH	25	03	F0	6				35	C	54	27
18A0	fwd WH	26	03	F0	7				41	3	54	35
18A4	rev WH	27	03	F0	7				41	7	54	36
	•			•						•		•
18A0	fwd WH	35	03	B0	5					3	54	-1
18A4	rev WH	36	03	B0	5					7	54	-1

5

10

15

Table 7, above, shows a portion of a typical secondary constant array 42 of commands for the INCOM native language. Table 7, like Table 6, assumes an exemplary base address of 40000H, although a wide range of base addresses may be employed. The first three columns of Table 7 are for ease of illustration and are not part of the exemplary array 42. Each row is a record, which record consists of ten elements: (1) cmd/inst; (2) sub cmd; (3) # msgs; (4)-(7) Expand Buf #; (8) offset bytes; (9) frmt #; and (10) ndx lnk, with each column being an element of the record. In this array 42, unlike array 40 of Table 6, objects are not in monotonically increasing order.

Entry into this secondary array 42 is initially via the '2ndry cmd ndx' of the primary constant array 40 of Table 6. Once entered, progression through this array 42 is determined by the 'ndx lnk' record element. Calculation of an index to a record in this array 42 is not required.

Figure 5 shows the main loop 100 of the μ P 80 of the mMINT module 20 of Figure 4. Figure 5 also shows the 'MainState' machine of this module. The main loop 100 is the highest level state machine of the mMINT module 20. This state machine has two states: (1) handle query; and (2) respond to query. After starting, at 102, on power up, the μ P 80 initializes the micro-controller 72, at 104. The step 104 includes initialization of: (1) μ P 80 I/O ports 90,88; (2) the Modbus network system including UART 82; (3) the INCOM network system including INCOM port 84; (4) other serial communications (not shown); (5) serial EEPROM 115, which is part of MEM 86; (6) a μ P timer interrupt (not shown); (7) system status bits (not shown); (8) system variables (not shown); (9) diagnostic counters (not shown); and (10) the query handler 130 of Figures 6A-6C. Next, at 106, the baud rate selector switches SW2 96 are read, and the Modbus baud rate is set, at 108, in the UART 82.

At 110, the framing protocol of any received Modbus message is suitably verified. Next, at 112, the INCOM language message processor 200 (Figure 6D) is serviced. The message processor 200 translates INCOM data formats to Modbus data formats. It also creates an array of data bytes for the query response handler to send to the master 4. If there is no work for the message processor, then it simply returns to the main state or loop 100. Then, at 114, the handler for the serial EEPROM 115 of Figure 4 is serviced. The serial EEPROM 115 is advantageously employed for non-volatile storage of various values. If there is no service to perform, then the EEPROM handler simply returns to the main state or loop 100.

At 116, one of the two main states is selected. One possible state is associated with the Modbus query response handler 300 of Figure 7, while a second possible state is associated with the Modbus query handler 130 of Figures 6A-6C. Path 118 is selected for handling a Modbus query (Figures 6A-6C), while path 124 is selected for handling a Modbus query response (Figure 7). If path 118 is taken, then, at 120, the Modbus query handler state machine is serviced. Exit of this state associates a 'MainState' variable with the query response handler 300 (Figure 7). Then, at 122, it is determined if it is time (e.g., once per second) to toggle the human machine interface heart beat LED 70 of Figure 2. After step 122, step 106 is repeated.

Otherwise, if the known command is not in the primary constant array of commands 40 at 144, then the number of the command record in the secondary constant array of commands 42 is obtained, at 150, from the 'learned commands' array. Next, at 152, the secondary command index is obtained from the primary constant command record (*i.e.*, from '2ndry cmd ndx' of Table 6). Then, at 154, a search variable is set to the starting secondary command index from step 152. At 156, it is determined if the search variable value of step 154 is equal to the number (*e.g.*, as shown by the 'nbr' value in Table 7) of the command in the secondary constant array of commands 42. If so, at 158, then the INCOM command record is obtained from the secondary constant array of commands 42 as pointed to by the search variable value. Next, at 148, the INCOM command record is placed in an INCOM command launch buffer (not shown). On the other hand, if the search variable value of step 154 is not equal to the number of the command in the secondary constant array of

commands 42, then, at 160, the search variable is set (*e.g.*, by the 'ndx lnk' value) to index to the next command record from the record pointed to by the search variable.

After step 148, it is determined, at 162, if all objects in the Modbus request have been considered. For example, there may be multiple objects requested by the Modbus master 14 of Figure 2 that can be obtained from an INCOM device by a single INCOM command. The commands for such objects, in the command launch buffer, are identical. When these commands are linked, the offset to each object in the INCOM device response buffer can be obtained from the value of the associated element (*i.e.*, "offset (bytes)") in the command record. For example, if the Modbus request pertains to only one object (*e.g.*, phase A current, IA), then step 164 is executed. Otherwise, if the Modbus request pertains to more than one object (*e.g.*, phase A current, IA; phase B voltage, VB), then step 168 is executed to consider the next object's address. Then, step 140 is repeated.

On the other hand, if all objects were considered at 162, then the identical commands in command launch buffer are linked at 164. Finally, a variable 'maxCmd' is set to the number of INCOM commands to launch, at 166, before execution resumes at 167 of Figure 6C.

Referring to Figure 6C, at 167, it is determined if the number of INCOM commands launched is equal to the 'maxCmd' variable from step 166 of Figure 6A. If so, then at 170, it is determined if the message processor 200 (Figure 6D) is finished processing the last message. The message processor 200 includes a state machine that formats (*e.g.*, floating point format, fixed point format) the INCOM language object to the Modbus object format. The state employed is a function of record element 'frmt #' of the primary or secondary constant arrays of commands 40,42. If the message processor 200 is finished at 170, then the variable 'MainState' is set to the query response handler, and the query response handler state is set to 'respond to read' at 172. Otherwise, the routine 130 returns at 175.

On the other hand, if the number of INCOM commands launched is not equal to the 'maxCmd' variable, at 167, then it is determined if the INCOM device message buffer is empty at 176. If it is not empty, then the routine 130 returns at 177. Otherwise, the INCOM command is loaded into the launch queue and is

launched onto the INCOM network 24 at 178. If the INCOM port is timed out (*e.g.*, no response is timely received from the INCOM slave device) at 180, then, at 182, a suitable exception code is placed into the Modbus response buffer at 182. Next, at 184, the variable 'MainState' is set to the query response handler 130, and the query response handler state is set to 'send exception'. Then, the routine 130 returns at 174.

On the other hand, if there was no timeout at 180, then it is determined from the '#msgs' element of the INCOM command record (Table 6) if all INCOM messages were received at 186. If so, then it is determined if the INCOM device understands (*i.e.*, if no NACK was returned and the INCOM device responded with the data) the command at 188. If yes, then the INCOM device response buffer is copied to a 'process' buffer at 190. Next, the message processor 200 is activated at 192. Then, the number of INCOM commands launched is incremented at 194, after which step 167 is repeated to determine if the number of commands launched is equal to the variable 'maxCmd'.

Otherwise, if the INCOM device does not understand the command at 188, then the index is set to the next INCOM command as contained in the command launch buffer (as discussed at 148 of Figure 6B) at 196. Then, the next INCOM command is obtained at 198 after which step 178 is executed to load the INCOM command into the launch queue and launch it onto the INCOM network.

Referring to Figure 6D, the message processor 200 of the mMINT module 20 is shown. The message processor 200 begins, at 202, after which it is determined whether the message processor 200 was activated, at 204. The message processor 200 is de-activated at 226 and is activated at 192 of Figure 6C. Next, at 206, one of two states 208,210 are selected. The establish state 208 is selected at 192 of Figure 6C and the convert state is established at 214.

If the establish state 208 is selected, then, the linked information is established as obtained from the launch buffer at 212. This information includes the offset into the receiver buffer, the offset into the Modbus response buffer, and the format. Then, the message processor state is changed to convert at 214. Finally, the message processor 200 returns at 216.

On the other hand, if the convert state 210 is selected, at 206, then it is determined if processing of all linked messages is finished, at 218. This processing is finished when the index to the linked object is equal to -1. If not finished, then, at 220, three variables are initialized, including: (1) variable 'z' is set to the index to the linked object in the launch queue; (2) variable 'm' is set to the offset to the message in the INCOM response buffer; and (3) variable 'zP' is set to the offset into the Modbus response buffer. Next, at 224, the function 230 is executed in order to determine the variable 'inoc' as a function of convertFormat(z,m,zP). The variable 'inoc' is the index to the next object to convert. The message processor 200 returns at 216.

Otherwise, if processing of all linked messages is finished, at 218, then the message processor is de-activated and the 'receive msg processor buffer empty' flag is set at 226. Then, the message processor 200 returns at 228.

The convertFormat function 230 begins, at 232, by determining whether there is a convert status object. This is a test of whether the query requested the object at register 41200 (status). Next, at 234, the variable 'status' is obtained. This variable includes three bytes designated as 'cause', 'primary cause' and 'secondary cause'. Then, at 236, the variable 'status' is placed in the Modbus response buffer based upon the offset variable 'zP'. Next, at 238, the variable 'inoc' is determined. This is an additional part of the linked information from 212 of Figure 6D. The variable is the index into that linked information. The index is initialized at 212. Finally, the variable 'inoc' is returned at 240.

On the other hand, if there was no convert status object, at 232, then the format from the linked object is obtained based upon the index variable 'z' at 242. Next, at 244, the format state (*e.g.*, state #13 or #54) is selected. This format state is part of the linked information from 212 of Figure 6D. If the format state is #54, at 248, then an energy object is converted to a 64 bit variable at 250 before being placed in the Modbus response buffer at 236. Otherwise, if the format state is #13, at 246, then it is determined if there is a valid 24-bit floating point object at 252. The INCOM 24-bit floating point format provides a specific bit that, when set, specifies a valid 24-bit floating point number. The INCOM product sets this bit. If valid, then it is determined whether to convert the object to an IEEE floating point variable at 254.

If the related query register is 412xx (wherein xx is a don't care term), then it is to be an IEEE floating point conversion. Otherwise, if the related query register is 418xx, then it is to be a fixed point conversion. If so, then the object is converted to an IEEE floating variable at 256 before being placed in the Modbus response buffer at 236.

- 5 Otherwise, the object is converted to a fixed-point variable at 258 before 236 is executed.

On the other hand, if there is no valid 24-bit object at 252, then the 'MainState' variable is set to the response handler at 260. Finally, the 'response handler' state is set to 'send' exception code '2' at 262 before the message processor
10 200 returns at 216.

Figure 7 shows the query response handler 300 of the μ P 80 of the mMINT module 20 of Figure 4. The handler 300 functions to send various buffers to the Modbus master 14 of Figure 2. The handler 300 begins, at 302, after which it is determined whether to respond with an exception code, at 304. As discussed in
15 connection with 182 of Figure 6C, an exception code is issued as a response from an error handler situation. If a response is needed, then, at 306, the exception counter is advanced for the INCOM language device. Otherwise, and after 306, the proper one of the states 310,312,314,342,344,346 is selected at 308. The query handler sets the state of the query response handler state machine at 172 and 184 of Figure 6C. If the
20 byte sent state 310 is selected, then it is determined at 318 if all bytes have been sent (e.g., the number of bytes in the Modbus response buffer is established by counting bytes in the buffer). If so, then it is determined from variable 'write data to EEPROM' being true, if data is to be written to EEPROM 115 at 320. At 196 of Figure 6C, the code related to which command was used is selected. That code is
25 written to EEPROM in the learned commands array. Also, the bit 'write data to EEPROM' is set at 196. If the test at 320 is met, then it is determined if this is the first execution of step 322 since the response handler state was first entered to send the contents of the present response buffer to the Modbus master 14. If so, then the variables and data are suitably set up for the EEPROM handler at 324. When the
30 EEPROM handler is finished, it changes variables such that 'write data to EEPROM'

is false, after which the handler 300 returns at 326. Otherwise, after 322, the routine returns at 326.

On the other hand, if 'write data to EEPROM' is false at 320, then the variable 'MainState' is set to the query handler at 328. Next, at 330, if the mMINT module 20 is controlling a circuit breaker via the query handler, or if it is servicing a pass through response, or if it is adjusting non-volatile RAM of the μ P 80, then the handler returns at 332. Otherwise, at 334, the query handler state variables are changed in order that it is waiting for a query, after which it returns at 332.

If the state 312 for a Modbus format breaker control response was selected at 308, then that response is prepared at 336, and the state is changed to 'byte sent' at 338, after which the handler 300 returns at 332. Similarly, if the state 314 for a Modbus format read query request response was selected at 308, then that response is prepared at 340, and the state is changed to 'byte sent' at 338, after which the handler 300 returns at 332.

If the state 342 for a Modbus format pass through response was selected at 308, then that response is prepared at 348, and the state is changed to 'byte sent' at 338, after which the handler 300 returns at 332. Similarly, if the state 344 for a Modbus format exception code response was selected at 308, then that response is prepared at 350, and the state is changed to 'byte sent' at 338, after which the handler 300 returns at 332. In a like manner, if the state 346 for a Modbus format diagnostic response was selected at 308, then that response is prepared at 352, and the state is changed to 'byte sent' at 338.

The main loop 100 of Figure 5, the query handler 130 of Figures 6A-6C, the message processor 200 of Figure 6D, and the query response handler 300 of Figure 7 form a communication routine 354 for the μ P 80 of Figure 4. The communication routine 354 receives a request based upon the register map 44 of Figure 2 through the Modbus transceiver 74 related to one or more of the values of one of the slave INCOM devices 26,28,30,32,34. The routine 354 sends a request based upon the slave's object/command map through the INCOM transceiver 76 related to the one or more INCOM device values. The routine 354 receives a response based upon the slave's object/command map through the INCOM

transceiver 76 related to the one or more INCOM device values. In turn, the routine 354 sends a response based upon the register map 44 through the Modbus transceiver 74 related to one or more INCOM device values.

The exemplary mMINT module 20 of Figure 2 responds to particular Modbus function codes including function codes 03H, 04H, 08H and 10H. A block of registers (*e.g.*, from the Register column(s) of Table 12) can be established for each INCOM slave device attached to the mMINT module 20. In the exemplary embodiment, the block size is 100 registers.

Function code 10H is employed to load a block of registers. The block is stored at the beginning register 45000. This register does not contain an object. Rather, the Modbus master 14 writes data to this register, with the data being Modbus registers (*e.g.*, 41202, 41204, 41206) of Table 12. Only the first object register is loaded with the block of registers. For example, if phase A current, IA, occupies registers 41202 and 41203, then only register 41202 is loaded with the block of registers.

The read function code (*e.g.*, 03H or 04H) and a register 45100 are employed to obtain the contents of the objects in the block of registers. The number of points (*i.e.*, registers) in the read query is typically twice the number of objects because each object may normally occupy two registers in the exemplary embodiment. However, energy objects occupy four registers and some objects occupy one register. The communication routine 354 is adapted to read a value from one of the INCOM devices, and to send the read value in the response based upon the register map 44 of Figure 2 through the Modbus transceiver 74 of Figure 4.

A feature of the mMINT module 20 is its capability to pass INCOM commands/data directly through to any (*e.g.*, 32) attached INCOM slave devices. As discussed above, the INCOM network 24 of Figure 2 includes a plurality of commands operatively associated with the slave devices 26,28,30,32,34. The communication routine 354 is adapted to receive a request through the Modbus transceiver 74 based upon one of the commands. Thus, under the IMPACC Communications Protocol, every INCOM slave device (*i.e.*, INCOM product) object and capability is available to the Modbus master 14 of Figure 2. When passing a

command or data through to an INCOM slave, the mMINT module 20 acts as a dumb Modbus slave. Without modification, it passes the command or data through to the INCOM slave device on the INCOM network 24. In the event the INCOM slave device responds, the mMINT module 20 saves the response until the Modbus master 14 queries for that response. The mMINT module 20 makes no modification to or interpretation of the INCOM product response data. The Modbus master 14 writes (beginning at register 46000) the INCOM product command/data using function code 10H. The protocol for passing a command through to an INCOM product is shown in Table 8.

Table 8

Byte #	Name	Contents
0	address	INCOM device address
1	fcn code	function code 10H
2	strt addr hi	high byte of starting address = 60H
3	strt addr lo	low byte of starting address = 00H
4	nbr regs hi	high byte of register count = 0
5	nbr regs lo	low byte of register count = 3
6	byte count	4
7	data	bit 7 is 1, bits 6-0 are the number of bytes from the INCOM device
8	data	BYTE0 of command
9	data	BYTE1 of command
10	data	BYTE2 of command
11	CRC lo	low CRC byte
12	CRC hi	high CRC byte

The protocol for passing data through to an INCOM product is shown in Table 9.

Table 9

	<u>Byte #</u>	<u>Name</u>	<u>Contents</u>
	0	address	INCOM device address
5	1	fct code	function code 10H
	2	strt addr hi	high byte of starting address = 60H
	3	strt addr lo	low byte of starting address = 00H
	4	nbr regs hi	high byte of register count = 0
	5	nbr regs lo	low byte of register count = 3
10	6	byte cnt	byte count = 4
	7	data	bit 7 is 0, bits 6-0 are the number of messages from the INCOM device
	8	data	BYTE0 of data message
	9	data	BYTE1 of data message
15	10	data	BYTE2 of data message
	11	CRC lo	low CRC byte
	12	CRC hi	high CRC byte

The Modbus master reads the INCOM product response to a pass through query beginning at register 46100 using either function code 03H or 04H.

The format of the read query response is shown in Table 10.

Table 10

	<u>Byte#</u>	<u>Name</u>	<u>Contents</u>
25	0	address	INCOM device address
	1	fct code	function codes 03H or 04H
	2	byte count	4 * number of messages from INCOM device
30	3	data hi	BYTE0 of response message 0 (<i>i.e.</i> , the first message)
	4	data lo	BYTE1 of response message 0
	5	data hi	BYTE2 of response message 0
	6	data lo	status of response message 0

35	n-3	data hi	BYTE0 of last (nn th) INCOM device response message
	n-2	data lo	BYTE1 of last response message from INCOM device
	n-1	data hi	BYTE2 of last response message from INCOM device
	n	data lo	status of last response message from INCOM device
	n+1	CRC lo	low CRC byte
40	n+2	CRC hi	high CRC byte

If the data of the response message has no errors, then the “status of response message” value is zero. On the other hand, if the mMINT module 20 received the response message with an over run error, a BCH error or a time out, then

Table 11

	Sub-Function		
	No. (decimal)	Name	Address for the Query
5	0	echo query	mMINT address 248
	1	restart communications	INCOM device address
	4	force listen	INCOM device address
	10	clear counters	mMINT address 248
10	11	bus message count	mMINT address 248
	12	communication error count	mMINT address 248
	13	exception error count	INCOM device address
	14	slave message count	INCOM device address
	15	slave no response count	INCOM device address
15	16	slave NAK count	INCOM device address
	17	slave busy count	INCOM device address
	18	UART over run error count	mMINT address 248
	20	clear UART over run	mMINT address 248
		error count	
20	22	INCOM BCH error count	INCOM device address
	23	INCOM over run count	INCOM device address
	24	UART framing error count	mMINT address 248
	25	UART noise error count	mMINT address 248
	26	UART over run error count	mMINT address 248
25			

Under certain circumstances, the mMINT module 20 will return an exception code in the response. Those exemplary codes include: (1) 01H if the function in the query is not supported by the mMINT module; (2) 02H if the data (object) register is illegal; (3) 03H if the data value in the query is illegal; (4) 04H if the slave INCOM product fails (*e.g.*, a time out); (5) 05H (ACK) is returned under suitable circumstances; (6) 07H (NACK) if the mMINT module cannot perform the requested function; and (7) 84H if only a partial register is used in the query.

The Modbus register map 44 for INCOM products is shown in Table 12, which includes an exemplary listing of INCOM products for interface by the mMINT module 20. As a result of the pass through feature of the mMINT module 20, all INCOM product objects are accessible by the Modbus master 14.

Table 12

Objects - (complete list)		Units	Register		INCOM Products - (partial list)									
Name	numeric		IEEE float	Fixed point (FP)	FP scale factor	IQ-200	DP-4000	IQ Analyze	IO Data	IQ Data Plus	Digitup 810	Digitup 910	Digitup 1150	IQTransfer II
prod ID	prod ID		4127A or 4187A			x	x	x	x	x	x	x	x	x
status cause	primary		41200 or 41800 hi byte			x	x	x	x	x	x	x	x	x
	secondary		41200 or 41800 lo byte			x	x	x	x	x	x	x	x	x
	cause		41201 or 41801 hi byte			x	x	x	x	x	x	x	x	x
current	I _A	A	41202	41802	10	x	x	x	x	x	x	x	x	
	I _B	A	41204	41804	10	x	x	x	x	x	x	x	x	
	I _C	A	41206	41806	10	x	x	x	x	x	x	x		
	I _G	A	41208	41808	10			x			x	x		
	I _N	A	4120A	4180A	10			x			x	x		
	I _{avg}	A avg	4120C	4180C	10									
	peak I _A demand	A	41220	41820	10		x							
	peak I _B demand	A	41222	41822	10		x							
	peak I _C demand	A	41224	41824	10		x							
L-L voltage	V _{AB}	V	4120E	4180E	10	x	x	x	x	x		x	x	
	V _{BC}	V	41210	41810	10	x	x	x	x	x		x	x	
	V _{CA}	V	41212	41812	10	x	x	x	x	x		x	x	
	V _{LLavg}	Vavg	41214	41814	10			x						
L-N voltage	V _{AN}	V	41216	41816	10	x	x	x	x	x			x	
	V _{BN}	V	41218	41818	10	x	x	x	x	x			x	
	V _{CN}	V	4121A	4181A	10	x	x	x	x	x			x	
	V _{LN}	Vavg	4121C	4181C	10			x						
N-G voltage	V _{NG}	V	4121E	4181E	10			x						
power	power	W	41276	41876	1	x	x	x			x	x	x	
	demand	W	41264	41864	1	x	x	x			x	x	x	
	real 3 ph	W	41228	41828	1	x	x	x					x	
	reactive 3 ph	VAR	4122A	4182A	1	x	x	x					x	
	apparent 3 ph	VA	4122E	4182E	1	x	x	x					x	
	A ph	W	41238	41838	1	x		x						
	B ph	W	4123A	4183A	1	x		x						

TABLE 12-06-660

Objects - (complete list)		Units	Register		INCOM Products - (partial list)									
Name	numeric		IEEE float	Fixed point (FP)	FP scale factor	IQ-200	DP-4000	IQ Analyze	IQ Data	IQ Data Plus	Digitip 810	Digitip 910	Digitip 1150	IQ Transfer II
power	C ph	W	4123C	4183C	1	x		x						
	reactive A ph	VAR	4123E	4183E	1	x		x						
	reactive B ph	VAR	41240	41840	1	x		x						
	reactive C ph	VAR	41242	41842	1	x		x						
	apparent A ph	VA	41244	41844	1	x		x						
	apparent B ph	VA	41246	41846	1	x		x						
	apparent C ph	VA	41248	41848	1	x		x						
power factor	pf	pf	41278	41878	10	x	x	x			x	x	x	
	displacement 3 ph	pf	4122C	4182C	100									
	displacement A ph	pf	4124A	4184A	100	x		x						
	displacement B ph	pf	4124C	4184C	100	x		x						
	displacement C ph	pf	4124E	4184E	100	x		x						
	apparent A ph	pf	41250	41850	100	x		x						
	apparent B ph	pf	41252	41852	100	x		x						
	apparent C ph	pf	41254	41854	100	x		x						
	apparent	pf	41230	41830	100	x	x	x					x	
energy	forward	Wh	412A0	418A0	10	x	x	x					x	
	reverse	Wh	412A4	418A4	10			x					x	
	net	Wh	412A8	418A8	10			x					x	
	apparent	VAh	412AC	418AC	1	x	x	x					x	
reactive energy	lead	VAR _h	412B4	418B4	1	x	x	x					x	
	lag	VAR _h	412B0	418B0	1	x	x	x					x	
	net	VAR _h	412B8	418B8	1			x					x	
frequency	freq	Hz	41232	41832	10	x	x	x	x	x			x	
source 1	V _{AB}	V	41266	41866	10									x
	V _{BC}	V	41268	41868	10									x
	V _{CA}	V	4126A	4186A	10									x
	freq	Hz	4126C	4186C	10									x
source 2	V _{AB}	V	4126E	4186E	10									x
	V _{BC}	V	41270	41870	10									x
	V _{CA}	V	41272	41872	10									x
	freq	Hz	41274	41874	10									x
K-factor	K-factor		41234	41834	1		x						x	
THD factor	THD factor		41236	41836	1		x						x	

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Figure 8 shows a mMMNT (modbus Master Modbus Network Translator) module 20' in accordance with another embodiment of the present invention. This mMMNT module 20' is similar to the mMINT module 20 of Figures 2 and 4, except that the slave INCOM network 24 is replaced by a slave Modbus network 24'. The module 20' advantageously maps identical Modbus objects located in different Modbus registers (in the lower level Modbus network 24') to a particular Modbus register in the upper level Modbus network 12. The module 20' includes a UART 84' for interfacing a second Modbus transceiver 76' for communication through the second Modbus connector 56'. The module 20' includes a primary constant array (P) 40' of commands, which is a constant array of records of native language Modbus elements employed to obtain a specific object from a slave device, which speaks the native Modbus language. In this example, the module 20' does not employ a secondary constant array (S) of commands.

In this manner, there are associated cost advantages, including, for example: (1) reduced documentation cost; (2) no reprogramming of the Modbus master 14 when another slave device, such as 34', is attached thereto; and (3) the capability of attaching many more slave devices, such as 16,18, to the upper level Modbus network 12 because of the reduced electrical load on that network (*i.e.*, because the slave devices 26',28',30',32',34' are attached to the lower level Modbus network 24'). Furthermore, in accordance with the present invention, for the Modbus master 14, the current IA, for example, from any of the slave devices 26',28',30',32',34' is always in register 1202H. However, on the lower level Modbus network 24', the current IA for the slave device 26' is in Modbus Register 12A4H; the current IA for the slave device 28' is in Modbus Register 1145H; the current IA for the slave device 30' is in Modbus Register 1098H; and the current IA for the slave devices 32',34' is in Modbus Register 1202H.

While specific embodiments of the invention have been described in detail, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be

Climatic data (1971-1990)	
Mean annual temperature	15.0
Mean annual precipitation	1500
Mean annual relative humidity	78
Mean annual wind speed	2.5
Soil data	
Soil type	Andisol
Soil texture	Clay
Soil pH	5.5
Soil organic matter	10
Soil nitrogen	0.1
Soil phosphorus	0.01
Soil potassium	0.1
Soil calcium	0.1
Soil magnesium	0.1
Soil sulfur	0.1
Soil iron	0.1
Soil zinc	0.1
Soil copper	0.1
Soil manganese	0.1
Soil boron	0.1
Soil sodium	0.1
Soil chloride	0.1
Soil fluoride	0.1
Soil iodine	0.1
Soil selenium	0.1
Soil tellurium	0.1
Soil bromine	0.1
Soil strontium	0.1
Soil barium	0.1
Soil lanthanum	0.1
Soil cerium	0.1
Soil praseodymium	0.1
Soil neodymium	0.1
Soil promethium	0.1
Soil samarium	0.1
Soil europium	0.1
Soil gadolinium	0.1
Soil terbium	0.1
Soil dysprosium	0.1
Soil holmium	0.1
Soil erbium	0.1
Soil thulium	0.1
Soil ytterbium	0.1
Soil lutetium	0.1
Soil hafnium	0.1
Soil tantalum	0.1
Soil tungsten	0.1
Soil rhenium	0.1
Soil osmium	0.1
Soil iridium	0.1
Soil platinum	0.1
Soil gold	0.1
Soil silver	0.1
Soil cadmium	0.1
Soil mercury	0.1
Soil lead	0.1
Soil tin	0.1
Soil antimony	0.1
Soil tellurium	0.1
Soil selenium	0.1
Soil arsenic	0.1
Soil phosphorus	0.1
Soil sulfur	0.1
Soil nitrogen	0.1
Soil carbon	0.1
Soil hydrogen	0.1
Soil oxygen	0.1
Soil silicon	0.1
Soil aluminum	0.1
Soil iron	0.1
Soil calcium	0.1
Soil magnesium	0.1
Soil potassium	0.1
Soil sodium	0.1
Soil chlorine	0.1
Soil fluorine	0.1
Soil bromine	0.1
Soil iodine	0.1
Soil strontium	0.1
Soil barium	0.1
Soil lanthanum	0.1
Soil cerium	0.1
Soil praseodymium	0.1
Soil neodymium	0.1
Soil promethium	0.1
Soil samarium	0.1
Soil europium	0.1
Soil gadolinium	0.1
Soil terbium	0.1
Soil dysprosium	0.1
Soil holmium	0.1
Soil erbium	0.1
Soil thulium	0.1
Soil ytterbium	0.1
Soil lutetium	0.1
Soil hafnium	0.1
Soil tantalum	0.1
Soil tungsten	0.1
Soil rhenium	0.1
Soil osmium	0.1
Soil iridium	0.1
Soil platinum	0.1
Soil gold	0.1
Soil silver	0.1
Soil cadmium	0.1
Soil mercury	0.1
Soil lead	0.1
Soil tin	0.1
Soil antimony	0.1
Soil tellurium	0.1
Soil selenium	0.1
Soil arsenic	0.1
Soil phosphorus	0.1
Soil sulfur	0.1
Soil nitrogen	0.1
Soil carbon	0.1
Soil hydrogen	0.1
Soil oxygen	0.1
Soil silicon	0.1
Soil aluminum	0.1
Soil iron	0.1
Soil calcium	0.1
Soil magnesium	0.1
Soil potassium	0.1
Soil sodium	0.1
Soil chlorine	0.1
Soil fluorine	0.1
Soil bromine	0.1
Soil iodine	0.1
Soil strontium	0.1
Soil barium	0.1
Soil lanthanum	0.1
Soil cerium	0.1
Soil praseodymium	0.1
Soil neodymium	0.1
Soil promethium	0.1
Soil samarium	0.1
Soil europium	0.1
Soil gadolinium	0.1
Soil terbium	0.1
Soil dysprosium	0.1
Soil holmium	0.1
Soil erbium	0.1
Soil thulium	0.1
Soil ytterbium	0.1
Soil lutetium	0.1
Soil hafnium	0.1
Soil tantalum	0.1
Soil tungsten	0.1
Soil rhenium	0.1
Soil osmium	0.1
Soil iridium	0.1
Soil platinum	0.1
Soil gold	0.1
Soil silver	0.1
Soil cadmium	0.1
Soil mercury	0.1